Use of Electronic Tag Data and Associated Analytical Tools to Identify and Predict Habitat Utilization of Marine Mammals

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LONG-TERM GOALS

Key to assessing the risk of naval activities (such as sound exposure) on marine animals is an understanding of where animals occur and what factors motivate these movements. The rapid advancement of electronic tracking and remote sensing technologies has enabled researchers to link pelagic predator movements and oceanic processes. This information is critical for understanding distribution and residence time of vertebrates within an ocean area and for managing interactions with anthropogenic activities. Marine predators interact with a dynamic ocean that change on time scales ranging from minutes to millennia. Knowledge of these movement interactions is incomplete but critical to understanding dynamic distributions, managing anthropogenic disturbance, and predicting responses to climate change. This proposal utilizes the largest database of existing marine vertebrate tracking and behavior data to build upon the significant advances in tag technology, data analyses and management accomplished under the Tagging of Pacific Pelagics (TOPP) program. This will be accomplished by establishing a behavioral baseline to assess the potential costs of displacement in terms of reduced foraging success. The project also involves a synthesis of electronic tracking and remote sensing data, focusing on a cross-taxa examination of marine predator distribution and movement patterns to identify hotspots, foraging patterns and movement corridors in the California Current.

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OBJECTIVES

1) Identify and map focal feeding, breeding, and migration routes.
2) Model spatio-temporal oceanographic habitat utilization and predict regions of animal occupancy and use based on oceanographic features.
3) Utilize this model framework to assess the impact of displacement from primary feeding areas due to disturbances (such as acoustic disturbance).

APPROACH

There are two distinct components to this effort, each of which addresses a project objective. First, we will use existing TOPP tracking data to generate overall utilization distributions (Figure 1) as well as single species distributions and further categorize track segments by behavioral state using a combination of state spaced models and the fractal landscape method to determine regions of area restricted search (ARS) (Jonsen et al. 2003; Jonsen et al. 2006; Tremblay et al. 2007). Next, we will model the links between oceanographic parameters and animal movement patterns. The output from these models will be used to develop predictive models of marine vertebrate distribution based on oceanographic parameters.

RESULTS

TOPP data reveal the high importance of the California Current Large Marine Ecosystem (CCLME) to all predators tagged. Annual migratory periodicity was evident in the movements of many tagged animals that showed fidelity to the CCLME (Figure 2).

Extended residency within the CCLME was revealed by examining tracks that spanned multiple seasons using a switching state-space model. Numerous species exhibited a strong attraction to the CCLME and undertook long migrations (> 2,000 km) from the western, central, or south Pacific basin (leatherback sea turtles, black-footed albatrosses, sooty shearwaters, bluefin tuna, and salmon sharks; Figure 2b). Species exhibited a seasonally recurring north-south migration (bluefin and yellowfin tunas, mako, white, and salmon sharks, blue whales, male elephant seals and leatherback sea turtles; The mechanisms and cues underlying fidelity to seasonally-modulated migration pathways are not entirely known, but may represent a capacity to discriminate among areas of seasonal significance for foraging, or reproduction.

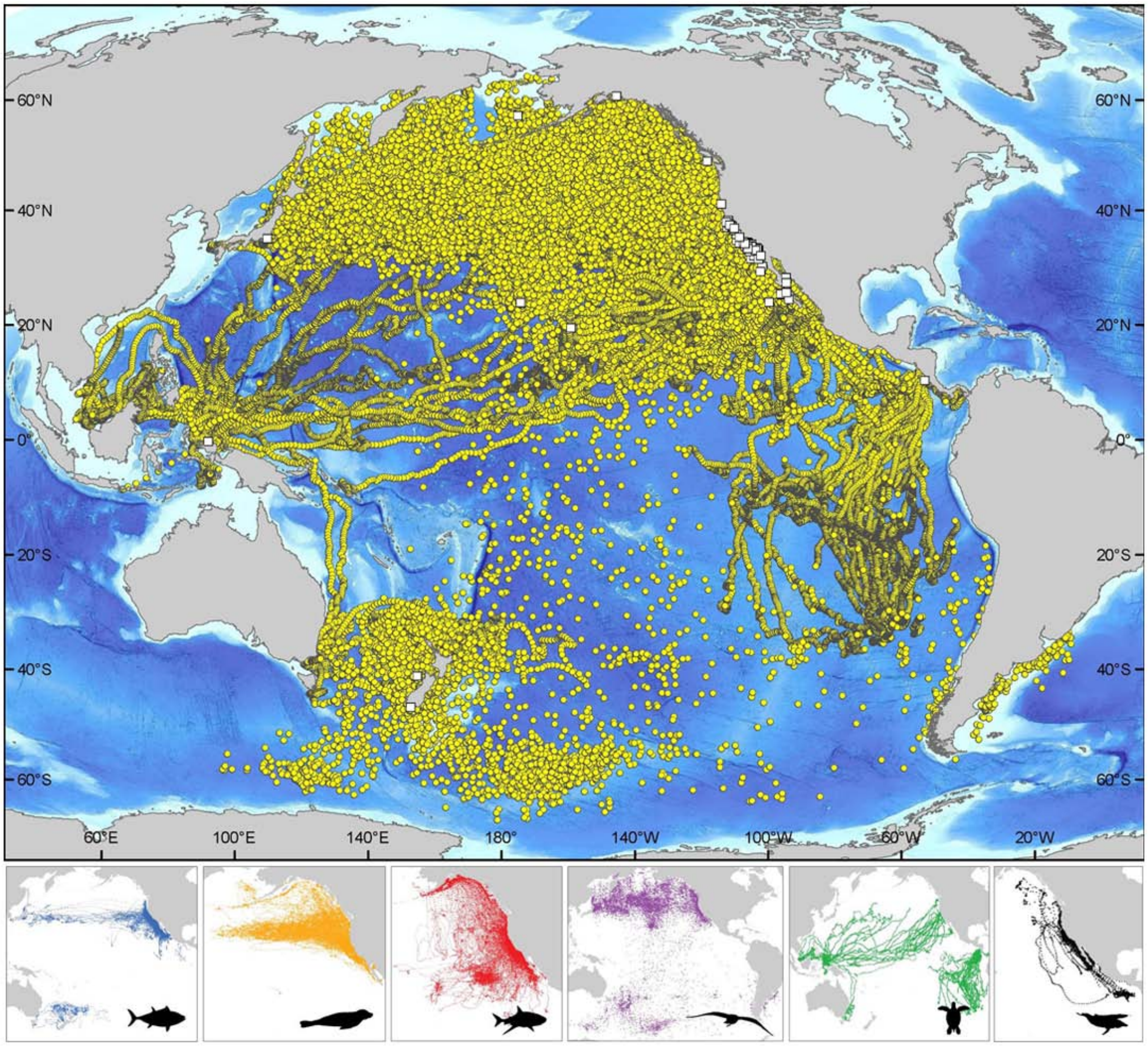

Figure 1. All TOPP species state space position estimates and distribution from electronic tagging. (a) Daily mean position estimates (circles) and deployment locations (squares) of all tagged species. (b) Daily mean position estimates of the major TOPP guilds. Tunas (yellowfin, bluefin, and albacore), pinnipeds (elephant seals, sea lions, and fur seals), sharks (salmon, white, blue, common thresher, and mako sharks), seabirds (Laysan and black-footed albatrosses and sooty shearwaters), turtles (leatherbacks and loggerheads), and cetaceans (blue, fin, and humpback whales).

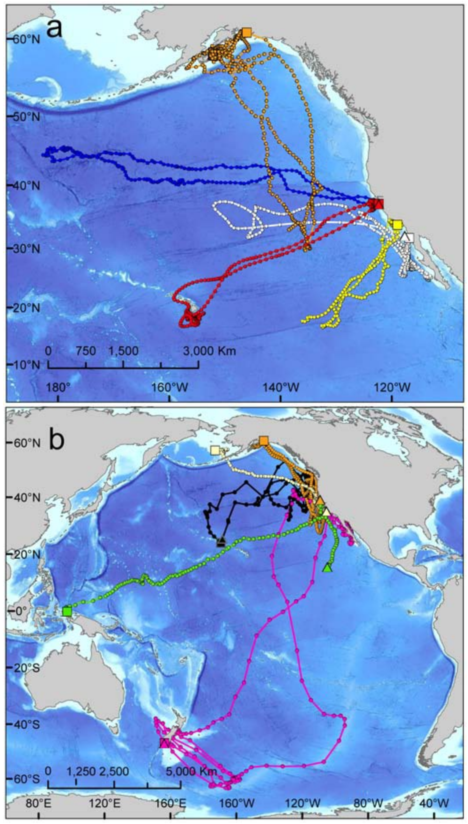

Figure 2. Fidelity and attraction to the California Current Large Marine Ecosystem. (a) Examples of pelagic predators released and electronically tracked in the CCLME that show fidelity to deployment locations. Release location (square), pop up end point location (triangle), and daily mean positions (circles) of the following species: yellowfin tuna (yellow), bluefin tuna (white), white shark (red), elephant seal (blue), and salmon shark (orange). (b) Individual tracks of pelagic animals released >2000 km away from CCLME that are indicative of across basin or ecosystem attraction of the eastern Pacific. Leatherback turtle (green), sooty shearwater (pink), fur seal (pale yellow), black-footed albatross (black), and salmon shark (orange).

Accurate description of multi-species density patterns requires that individual tracks are representative of the spatial coverage during the time period examined and that individuals and species are equally represented. For all species, the number of tagged individuals decreased with time since deployment. Tag attrition occurred due to loss of battery power, biofouling, premature detachment, or mortality events. Tracking durations also varied as a result of differences in species-specific life history patterns. To account for a bias toward tag deployment locations when building hot spots, tag attrition, and for variation in sample size among taxa across years, we applied time-weighting and species-normalization schemes prior to examining multi-species density patterns. The resulting all-taxa density map identifies the major areas of high use for large marine predators in the eastern North Pacific (Figure 3a), and areas of favorable habitat within the exclusive economic zones (EEZs) of the western North American continent (Figure 3b). The CCLME emerges as a highly retentive area for species tagged there, and an attractive area for animals undergoing long migrations from the western and central North Pacific and Gulf of Alaska (Figure 2a and b). The productive upwelling zone of the CCLME contains large biomasses of sardines, anchovies, squid, and krill, providing a predictable forage base for top predators. The North Pacific Transition Zone (NPTZ) is another complex region

encompassing an abrupt north-to-south transition between subarctic and subtropical water masses and is also revealed to be a major east-west migration corridor and retentive foraging region for multiple TOPP species (elephant seals, salmon sharks, Laysan and black-footed albatrosses, bluefin tuna, and northern fur seals). The NPTZ has previously been shown to be important habitat for loggerhead and olive ridley sea turtles as well as blue sharks and swordfish.

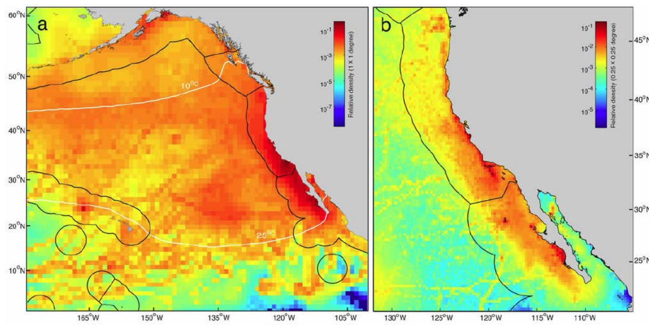

Figure 3. Predator density maps. (a) Density of large marine predators within the eastern North Pacific. (b) Density of large marine predators within the CCLME at a 0.25 x 0.25 degree resolution. Sea surface temperature contours in (a) are denoted by solid white lines. Exclusive economic zones (EEZs) are denoted by solid black lines.

To examine which aspects of the biophysical environment putatively attract a wide range of predators, we explored both presence/absence and relative habitat use with generalized additive mixed models (GAMM). We examined the collective response of 16 marine predator species to environmental covariates. In the binary presence/absence model, predator incidence showed a strong positive relationship with SST, across a broad temperature range, peaking near 15˚C, while habitats with the highest probability of occupancy included both low (< -2.52 ln mg·L^{-1}) and high (-0.92 ln mg·L^{-1}) chlorophyll-*a* (Figure 4a, 4b). These relationships show that the animals occupy a small portion of the total available habitat in the North Pacific, which was dominated by warm oligotrophic waters. The relative habitat use model revealed preferential occupancy of regions characterized by high surface chlorophyll-*a* and, secondarily, warmer surface water temperatures (Figure 4c, d). Combined results from these models are consistent with the hypothesis that some species are thermally constrained in habitat selection (Figure 4a) whereas all species had higher densities in regions of enhanced productivity (Figure 4d). Guild-specific climatology plots suggest that seasonal temperature changes trigger north-south migrations (e.g., between Baja, the Southern California Bight, and central California), with migration terminuses coincident with high densities of chlorophyll-*a*. The animal movement patterns recur predictably over multiple years. The relationship between relative use and SST from our behavioral data are consistent with global species richness distributions revealed from survey and fisheries data of diverse taxa, including zooplankton, tunas and billfish, and cetaceans and may represent mean thermal tolerances across multiple taxa.

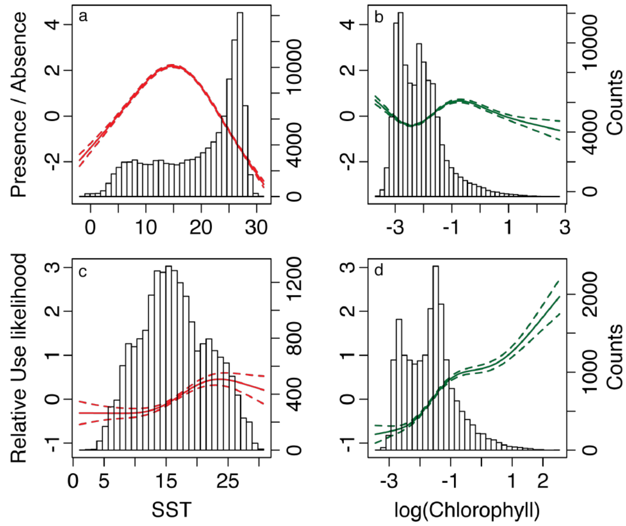

Figure 4. Environmental correlates of large predator density. Generalized additive mixed model response curves from (a,b) binary presence/absence and (c,d) relative use models from the eastern Pacific. Model response is shown for (a,c) temperature (solid red lines), (b,d) chlorophyll a (solid green lines), and dashed lines represent 95%.

To better understand how closely related taxa use various marine realms we examined thermal habitat use from *in-situ* SST measurements for sympatrically occurring species within three guilds (albatrosses, tunas, and lamnid sharks). We used linear mixed effects models to account for the repeated SST measurements within individuals. Laysan and black-footed albatrosses (genus *Phoebastria*), tagged at the same breeding colony in the northwestern Hawaiian Islands, showed distinct geographic and thermal separation in habitat use during the post-breeding phase (Figure 5a). Black-footed albatrosses traveled to and remained within the CCLME and used a broader and warmer range of SSTs (17.84°C ± 0.55 s.e.), whereas Laysan albatrosses used a colder and narrower range (13.97°C ± 0.48 s.e.) in the western and central North Pacific (Figure 5a).

Pacific bluefin and yellowfin tunas (genus *Thunnus*) displayed niche overlap primarily in the Southern California Bight but bluefin tuna ranged farther north in the CCLME, with some individuals migrating to the eastern Pacific, and yellowfin tuna ranged farther south (Figure 5b). These differences in distribution were consistent with the estimated thermal preferences for the two species (bluefin 17.36°C ± 0.05 s.e.; yellowfin 21.55°C ± 0.16 s.e.; Figure 5b) and consistent with physiological differences in cardiac performance. Bluefin have an increased capacity to maintain beat-to-beat contraction of the heart at cooler temperatures than yellowfin.

Three Lamnid shark species (salmon, short-finned mako and white shark) displayed a distinct geographic separation of habitats that overlapped quarterly in the CCLME (Figure 5c). Salmon sharks used the most northern portion of the North Pacific including subarctic waters, whereas white sharks used the CCLME and offshore eastern central Pacific, and mako sharks inhabited the CCLME and Intertropical Convergence Zone. Salmon sharks were associated with significantly colder SSTs (11.74°C ± 0.46 s.e.) than either mako (18.18°C ± 0.65 s.e.) or white sharks (16.69°C ± 0.46 s.e.) (Figure 5c). Although mean SSTs for mako and white sharks were not significantly different, the

bimodal distribution of white shark SSTs reflected their distinct spatial distribution in nearshore and offshore habitats during different phases of their yearly cycle (Figure 5c).

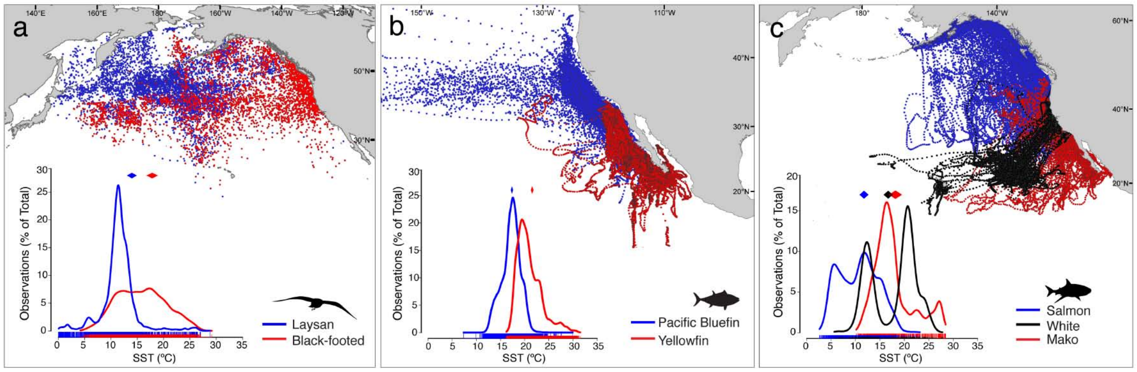

Figure 5. Niche separation within three predator guilds. Spatial distribution and thermal habitat use (inset) across three guilds of sympatric species (a) Laysan and black-footed albatrosses (n=55 individuals, 8.743 daily SSTs), (b) Pacific bluefin and yellowfin tunas (n=376 individuals, 75,177 daily SSTs), and (c) Lamnid sharks: salmon, mako, and white sharks (n=137 individuals, 12,971 daily SSTs). Sea surface temperature profiles are daily means of tag-derived SSTs. Linear mixed-effects model estimates of mean (±95% CI) SST for each species are displayed as diamonds at the top of each graph. The distribution of daily mean SSTs for each species is displayed along the x-axis.

IMPACT/APPLICATIONS

Critical to determining the impact of exposure to naval operations on marine animals is relating the intensity and duration of an exposure to the time animals spend in proximity to the source, and the biological function of that time. The proposed predictive models of critical marine animal habitat utilization are the essential behavioral components to determine whether and where naval operations might impact marine mammals and other marine vertebrates.

RELATED PROJECTS

JIP: Relating Behavior and Life Functions to Populations Level Effects in Marine Mammals: An empirical and modeling effort to develop the PCAD model. Contract JIP 22 07-23

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